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GAMMA-RAY BURST CLASSES FOUND IN THE RHESSI DATA SAMPLE

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Abstract. A sample of 427 gamma-ray bursts (GRBs), measured by the RHESSI satellite, is studied statistically to determine the number of GRB groups. Previous studies based on the BATSE Catalog and recently on the Swift data claim the existence of an intermediate GRB group, besides the long and short groups. Using only the GRBs durations T_{90} and χ^2 or F-test, we have not found any statistically significant intermediate group. However, the maximum likelihood ratio test, one-dimensional as well as two-dimensional hardness vs. T_{90} plane, reveal the reality of an intermediate group. Hence, the existence of this group follows not only from the BATSE and Swift datasets, but also from the RHESSI results.

Key words: gamma-rays: bursts

1. INTRODUCTION

Originally it was found (BATSE data: Kouveliotou et al. 1993; Konus-Wind data: Aptekar et al. 1998) that two GRB classes exist: a short one of duration $\lesssim 2$ s and a long one $\gtrsim 2$ s. They have different celestial distributions (Balázs et al. 1998, 1999; Mészáros et al. 2000a,b; Litvin at el. 2001; Mészáros & Štoček 2003; Vavrek et al. 2004, 2008), and they contain two different central engines (Balázs et al. 2003, 2004; Fox et al. 2005). Some articles deal or even point to the existence of three GRB classes in the BATSE database (Horváth 1998, 2002; Mukherjee et al. 1998; Belousova et al. 1999; Balastegui et al. 2001; Horváth et al. 2004, 2006; Chattopadhyay et al. 2007). Some authors conclude that the third class (of intermediate duration), observed by BATSE, is a bias caused by an instrumental effect, placing the intermediate group as a separate source population in doubt (Hakkila et al. 2000, 2004; Rajaniemi et al. 2002). On the other hand, recent papers by Horváth et al. (2008), Horváth (2009), and Huja et al. (2009) indicate that there is a statistically significant intermediate group in the Swift and

BeppoSAX datasets.

The purpose of this paper is to investigate the number of GRB groups in a dataset provided by the RHESSI satellite[1] which consists of 427 GRBs covering the period of 2002–2008. This issue is examined in more detail in the paper Řípa et al. (2009). We analyzed both one-dimensional distribution of GRB durations and two-dimensional plane of hardness ratio versus duration. To determine the number of GRB groups, standard statistical tests described by Trumpler & Weaver (1953), Press et al. (1992) and Zey et al. (2006) were used.

2. DATA SAMPLE

The Ramaty High Energy Solar Spectroscopic Imager (RHESSI) is a NASA Small Explorer satellite designed to study hard X-rays and gamma-rays from solar flares (Lin et al. 2002). Its spectrometer consists of nine Ge detectors (Smith et al. 2002) which are only lightly shielded, ensuring that RHESSI is also useful for detecting non-solar photons from any direction (Smith et al. 2003). The energy range for GRB detection extends from about 30 keV to 17 MeV. The effective area is around 150 cm^2 (Wigger et al. 2006). We used the RHESSI GRB List[2] and the Cosmic Burst List[3] to find 487 GRBs between 2002 February 14 and 2008 April 25. There is no automatic search routine, only if there is a message from any other instrument of the Interplanetary Network [4], the RHESSI data are searched for a GRB signal.

We chose a subset of 427 events with signal/noise ratio higher than 6 and derived count flux curves (with a time resolution higher than 10 % of the burst duration for the vast majority of our entire dataset) and count fluences from the rear detector segments (except number R2) of the spectrometer (Smith et al. 2002) in the energy band from 25 keV to 1.5 MeV.

3. DURATION DISTRIBUTION

First, we studied one-dimensional duration distribution of T_{90} (Kouveliotou et al. 1993; Fishman et al. 1994). The histogram consists of 19 bins on a decimal logarithmic scale (Figures 1 and 2). The uncertainty of T_{90} consists of two components. One is given by the count fluence uncertainty during T_{90} (δt_{s}), which is given by Poissonian noise, and the second one is the time resolution of derived light curves (δt_{res}). The total T_{90} uncertainty δt was calculated to be $\delta t = \sqrt{\delta t_{\mathrm{s}}^2 + \delta t_{\mathrm{res}}^2}$. We follow the method used by Horváth (1998) and fitted one, two and three log-normal functions and used the χ^2 test to evaluate these fits. The number of GRBs per bin is at least 5 (except the last bin). The fit with one log-normal function is highly unacceptable, because $\chi^2 \simeq 157$ for 17 degrees of freedom (*dof*). The fit with two log-normal functions ($dof = 14$) gives $\chi^2 = 19.13$ which imply a goodness-of-fit (*gof*) of 12%. The fit with three log-normal functions ($dof = 11$) gives $\chi^2 = 10.30$ which imply $gof = 41\%$. The assumption of two groups being represented by two log-normal fits is acceptable, the fit with three log-normal functions even more. The question is whether the improvement in χ^2 is statistically significant. To an-

[1] `http://hesperia.gsfc.nasa.gov/hessi`

[2] `http://grb.web.psi.ch`

[3] `http://www.ssl.berkeley.edu/ipn3/masterli.html`

[4] `http://www.ssl.berkeley.edu/ipn3/index.html`

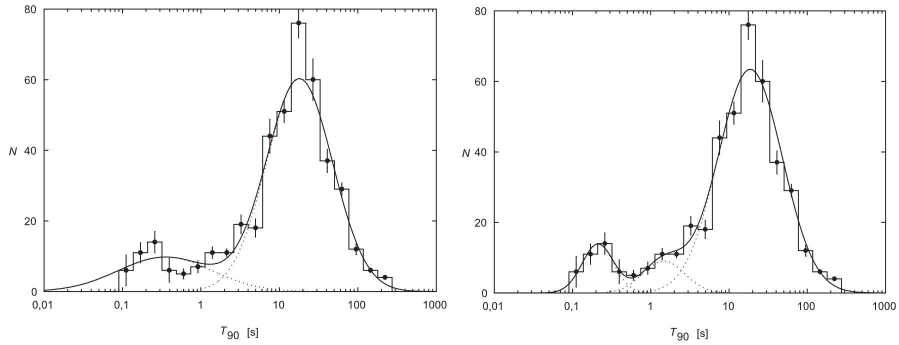

Fig. 1. Duration distribution of the 427 RHESSI GRBs (the number of bins is 19). The best fit with two log-normal functions (left panel) and with three log-normal functions (right panel). The error bars are standard deviations of the number of GRBs per bin for ten different simulated duration distributions described in the text.

swer this question, we used the F-test, as described by Band et al. (1997). The F-test gives a probability of 6.9% of the improvement in χ^2 being accidental. This value is remarkably low, but not enough to reject the hypothesis that the two log-normal functions are sufficient to describe the observed duration distribution. To determine how the T_{90} uncertainties affect our result, we randomly selected one half of the bursts and shifted their durations by the full amount of their uncertainties to lower values and the second half to higher values. We then compiled a histogram and recalculated the best-fit model parameters, χ^2 and F-test. Only three cases out of ten performed simulations gave F-test probability lower than 5% (namely 0.5, 2.0 and 3.5%). Therefore, on average, the improvement in χ^2 is insignificant and we cannot proclaim the acceptance of the three groups of GRBs by the χ^2 method.

Since the number of GRBs is just slightly higher than 5 for many bins, we also used the maximum likelihood method (see in Horváth 2002) to fit two and three log-normal functions. The difference of the logarithms of the likelihoods $\Delta \ln L = 9.2$ should be distributed as a half of the χ^2 for 3 degrees of freedom. From this value we infer that the introduction of a third group is statistically significant on the 0.036% level. To estimate, how the T_{90} uncertainties affect our result, we again generated ten different datasets randomly changing the durations by the full amount of their uncertainties. All ten simulations give probabilities which are in favour that introducing of the third group is accidental, much lower than 5% (in fact lower than 1%). Thus, the hypothesis of introducing a third group is acceptable when using a maximum likelihood fit.

4. HARDNESS RATIO VERSUS DURATION

A two-dimensional scatter plot (duration T_{90} vs. hardness ratio) is shown in Figure 2. The hardness ratio is defined as the ratio of two count fluences F in two different energy bands integrated over the time interval T_{90}. We used the energy bands (25–120) keV and (120–1500) keV, i.e., $H = F_{120-1500}/F_{25-120}$. Employing the maximum likelihood method (see Horváth et al. 2004, 2006 and references therein), we fit two and three bivariate log-normal functions. The difference in

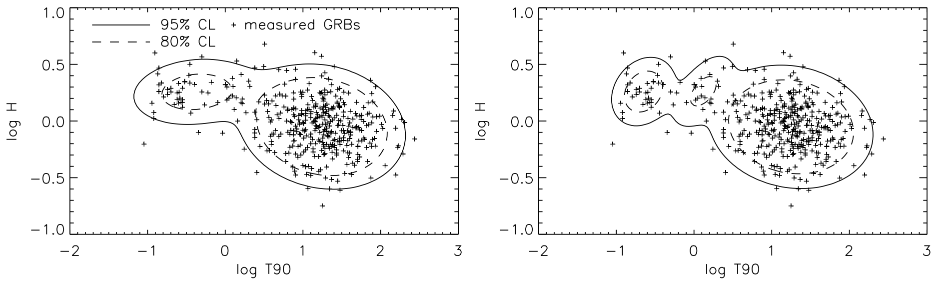

Fig. 2. Hardness ratio vs. T_{90} of the RHESSI GRBs with the best fit of two and three bivariate log-normal functions.

the logarithms of the likelihoods $\Delta \ln L = 10.9$ should be distributed as a half of the χ^2 for 6 degrees of freedom (Horváth et al. 2006) From this value we infer that the introduction of a third group is statistically significant on the 0.13% level. To estimate, how the uncertainties of GRB durations and hardness ratios effect our result, we generated ten different datasets randomly changed in durations and hardness ratios by the full amount of their uncertainties and recalculated the likelihoods. All ten simulations infer probabilities, of introducing the third group being accidental, lower than 5 %. Thus, the hypothesis of introducing the third group is again acceptable.

5. DISCUSSION AND CONCLUSIONS

The existence of an intermediate class from the RHESSI T_{90} distribution in not confirmed using the χ^2 method. However, the maximum likelihood ratio test on the same data reveals that the introduction of the third class is statistically significant. The hardness ratio versus duration plot for the RHESSI sample also demonstrates the existence of the third class. The typical durations are similar to those obtained with the one-dimensional analysis. The typical durations found for BATSE (Horváth et al. 2006) are roughly a factor of 2 longer than for RHESSI, but consistent for all three classes. The shorter durations of the RHESSI GRBs compared to the BATSE GRBs can be understood in the following way: for RHESSI, which is practically unshielded, the background is high (minimum around 1000 counts per second in the (25–1500) keV band) and varies by up to a factor of 3. Additionally, the RHESSI sensitivity declines rapidly below $\approx$50 keV. Weak GRBs (in the sense of counts per second) and soft GRBs are not so well observed by RHESSI. Since GRBs tend to be softer and weaker with time, they rapidly fall bellow the RHESSI detection limit, resulting in a shorter duration being inferred.

In the RHESSI dataset we confirm the BATSE result that short GRBs are on average harder than the long GRBs. The hardness of the intermediate class found for the RHESSI data is similar to that of the short GRBs. This is surprising since the intermediate class in the BATSE data was found to be the softest. This discrepancy might by explained by the different definitions of the hardness. The hardness H for the RHESSI data is defined as $H = F_{120-1500}/F_{25-120}$, whereas for the BATSE data $H = F_{100-320}/F_{50-100}$, where the numbers denote energy in keV. This means that hardnesses measure different behavior of bursts. The situation differs even more significantly if we compare hardnesses in the Swift and RHESSI databases, because the Swift hardnesses are defined as $H = F_{100-150}/F_{50-100}$ and

$H = F_{50-100}/F_{25-50}$ (Horváth et al. 2008; Sakamoto et al. 2008).

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